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ABSTRACT

The Australian Defence Force is improving the operational specificity of combat fitness assessment (CFA). A prototype CFA trial, conducted using 64 male soldiers of 3 Brigade, Townsville, allowed for the evaluation of both the CFA and the severity of heat strain experienced during physical training and assessment in northern Australia. Maximal aerobic ($\dot{V}O_{2max}$) and anaerobic (peak and 30-s mean) power were estimated by Beep and Wingate tests, respectively. Peak and 30-s mean powers and estimated $\dot{V}O_{2max}$ were 12.7 ±1.9 W·kg^{-1}, 9.3 ±1.0 W·kg^{-1} and 45.5 ±6.0 mL·min^{-1}·kg^{-1}, respectively. Of 31 soldiers marching 20 km with 35 kg load, 9 (29%) finished within the 4 hours available (WBGT =27.6°C). Of 51 soldiers marching 5 km with 20 kg load, 47 (92%) finished within 55 mins (WBGT=27.1°C). Heart rate (HR), $\dot{V}O_2$, gastrointestinal (T_{gi}) and skin (T_{sk}) temperature were recorded during the marches (n=5-19). Body weight, urine composition and volume and psychophysical indices of strain were obtained before and after the marches (n=9-50). At completion of the 5 and 20 km marches, high strain was evident from high HR (mean = 83% [5 km] & 89% [20 km] of HR_{max}), T_{gi} (38.6°C & 39.1°C), perceived body temperature (hot and very hot) and exertion (very hard and hard), and by instances of urinary protein and erythrocytes. The present estimates of $\dot{V}O_{2max}$ indicate that the ability of these infantry to operate in the tropics may be appreciably limited by their aerobic fitness. Further testing of soldiers' aerobic fitness will help determine the extent of this problem. Similarly, some soldiers experience very high heat strain during training and assessment. Endurance-related assessments should be conducted with personnel being rested and well hydrated, and with performance being indexed to environmental heat stress. Finally, heat strain can be monitored using gastro-intestinal radio-pill thermometry where appropriate.

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Executive Summary

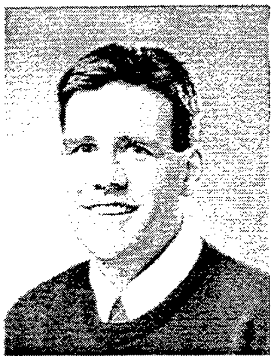
The Australian Defence Force (ADF) is attempting to improve the validity with which it assesses job-specific physical fitness of its personnel. The Defence Health Service Branch (DHSB) of the ADF is developing a new combat fitness assessment (CFA) for this purpose. The CFA, with its nine modules, is designed for use across many combat groups within the ADF, thereby also improving the defence-wide standardisation of fitness assessment. The Defence Science and Technology Organisation (DSTO) assisted in the initial CFA trial conducted in northern Australia by collecting and analysing performance data from some of the modules and by measuring physiological strain of a sample of soldiers. The data have assisted DHSB to modify the CFA prior to its implementation, and provide an indication of the severity of heat strain experienced by soldiers during training in tropical northern Australia.

The trial was conducted using 64 male soldiers of 3 Brigade, Townsville. Standard field assessments of aerobic fitness indicated that the average aerobic fitness of soldiers was only marginally above healthy, young adult male civilians. There was a low (29%) pass rate for the Infantry-only module of walking 20 km in 4 hours with 35 kg carried weight. Blistered feet and heat stress contributed to the high attrition. In contrast, there was a very high (93%) pass rate for all Corps walking 5 km in 55 min with 20 kg carried weight. Performances in the 5 km module may overestimate soldier ability to perform its operational equivalent - a march-in with full kit (at least 45 kg) - since the strain from exertion was, on average, already high in the humid conditions and was very high in some soldiers. Performances in the run-dodge-jump module were notably variable within and between Corps. All soldiers successfully completed the jerry-can carry module.

Methodologically, deep body temperature was measured readily using gastro-intestinal radio-pill thermometry. Of three systems used, the BCTM2 was preferred due to the ability to monitor multiple pills consecutively, the lack of data loss, ease of downloading data and the relatively small dimensions of the receiver unit, aerial and radio pill.

It is recommended, firstly, that the pass time for the 20 km march be indexed to environmental heat stress (eg. WBGT). Secondly, soldiers performing the CFA should be rested and well hydrated. Thirdly, since aerobic fitness appeared to be lower than is desirable for combat-ready soldiers operating in the tropics, testing the aerobic fitness of a larger sample of soldiers will help determine the extent of this performance limitation. Finally, the effects of environmental heat stress and load carriage on physiological strain of soldiers should be examined with a view to assessing the suitability of current work:rest cycle guidelines.

Authors



James D. Cotter (Jim)
Combatant Protection and Nutrition Branch

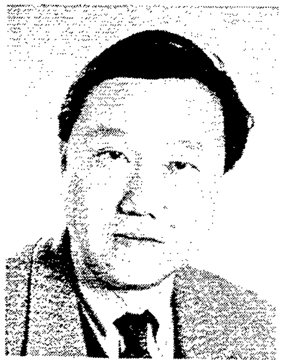
Jim graduated from the University of Otago (NZ) with a BSc in Physiology (1988), BPhEd in Kinesiology (1989) and MPhEd (1992) in physiological and epidemiological aspects of hypothermia. He moved to Australia (1993) and graduated from the University of Wollongong with a PhD in thermal physiology (1998). He was a lecturer (1997: physiology and exercise physiology) at the University of Wollongong, before joining the Personnel Protection and Performance Group of CPNB as a Research Scientist (1998) to evaluate physiological (especially heat-related) strain in ADF personnel, focussing on potential mechanisms for its reduction.

Warren S. Roberts
Combatant Protection and Nutrition Branch

Warren Roberts graduated from Swinburne University of Technology (AUS) with a B.App.Sci in Medical Biophysics and Instrumentation (1993), GradDip. in Social Statistics (1997) and a M.App.Sci in Haemorheology (1999). During both undergraduate and post-graduate studies he was associated with the Australian Institute of Sport (Canberra), working as an assistant/researcher on the physiological and biochemical assessment of elite athletes. He is currently providing technical support, as a Technical Officer Gr4, in the area of Combatant Performance in the Tropics.

Denys Amos
Combatant Protection and Nutrition Branch

Denys Amos graduated from the University of Durham (UK) in 1960 with a BSc (Hons) and MSc (1961) in organic chemistry. He has worked with ICI and the Science Research Council and has been attached to CBDE in the UK. At AMRL he has undertaken extensive research into decontamination and into protection of personnel against toxic chemicals. Until recently, Denys was a Principal Research Scientist and leader of a program on combatant performance in the tropics. He has been the principal investigator into the physiological assessment of soldier performance in the tropics and in the development of the Chemical and Biological Combat Suit.



Tony Wai Man Lau

Combatant Protection and Nutrition Branch

Tony Lau graduated with B.Sc (Hons) from the Chinese University of Hong Kong (CUHK), Hong Kong in 1979 majoring in Biology and Biochemistry. He obtained his M. Phil degree in Environmental Biology in 1981. Supported by a Croucher Foundation Scholarship (HK), he studied environmental toxicology at Melbourne University and was awarded a Ph.D. degree in 1987. After a short spell of employment as a senior chemist with the Unipath Pathology Laboratory, he joined MRL in 1985 and conducted pharmacological studies leading to improved prophylaxis and therapy of nerve agents. He is currently a Senior Research Scientist, managing a research program on personnel protection and physiological performance. He is also National Leader of the TTCP HUM TP6 Panel and Leader of the Environmental Physiology and Nutrition Focus Area of DSTO Human Factor Hub .

Stephen K. Prigg

Defence Health Service Branch

The majority of Steve's 24 years service with the ADF has been as an Army Physical Training Instructor (PTI). The final 3 years as a PTI were in the capacity of Chief Implementation Officer (CIO, WO1) at the Australian Defence Force Physical Training School (ADFPTS), HMAS Cerberus. In 1997, as a Captain, he was appointed to the Directorate of Clinical Policy in the Defence Health Service Branch (DHSB). As of 1999 he has been working as Staff Officer Injury Prevention, within Directorate of Preventive Health, DHSB. Steve's academic qualifications include a Diploma of Sport and Recreation (1981), a Diploma of Teaching (1984), a Bachelor of Education (1986) and a Graduate Diploma of Exercise Science (1993), and he is currently completing a Masters Degree in Public Health.

Contents

1. Introduction

The Australian Defence Force (ADF) requires all personnel to maintain a minimum level of physical fitness. This is determined annually by administration of a Basic Fitness Test, with performance in each module being graded for age and gender. Personnel in combat roles must also maintain sufficient combat-specific fitness to be deemed ready for combat, as determined by a combat fitness assessment (CFA, previously called a Combat fitness test (CFT)).

The Basic and Combat Fitness Assessments have been modified periodically to help (a) minimise injuries from training for (and participating in) assessment, (b) ensure that tests can be administered with minimal equipment, space and administrator expertise, and (c) reflect the actual physical demands of soldiers (ie. test validity). Nevertheless, there remains criticism of the assessments, including limited validity of assessment modules and a perception that the overall assessment of basic fitness is more physically demanding than is the CFA (Stephens, 1991). Therefore, Land Command Headquarters has tasked the Defence Health Service Branch (DHSB) to evaluate and recommend a CFA that validly assesses operation-specific physical fitness of combat soldiers. DHSB, in consultation with the Brigades, has developed a prototype CFA for evaluation. DSTO is involved in the evaluation of this CFA through assistance with data capture, analysis and interpretation.

Soldiers operating in tropical northern Australia are subjected to considerable heat stress from the combined effects of their physical work, their clothing and the ambient climatic conditions (Amos et al., 1998). There is potential for heat stress to be severe during endurance-related fitness assessments because of the long periods of high heat production associated with strenuous exercise. Therefore, a major role of DSTO in these trials has been the determination of the severity of physiological (especially heat-related) strain caused by participation in a CFA in tropical northern Australia. This is a report of the performance and strain data obtained from the first CFA trials conducted with 3 Brigade, Townsville in October 1998.

2. Methods

2.1 Soldiers

Initial validation trials were conducted on 27-29 October 1998 using 64 male soldiers from 3 Brigade, Townsville. Prospective volunteers were briefed on the purposes and demands of the CFA, including the procedures for collection of fitness and physiological data. Soldiers then provided their written, informed consent of participation. The volunteers were:

32 Infantry soldiers of 1RAR and 2RAR,	(Inf)
8 Artillery soldiers of Fourth Field Regiment,	(Art)
13 Armour soldiers of B Squadron 3rd/4th Cavalry Regiment	(Arm)
11 Engineer soldiers of 3rd Combat Engineer Regiment.	(Eng)

A sample of soldiers from these Corps was monitored for physiological and psycho-physiological strain during the endurance modules of the CFA. The protocols used were approved by the Australian Defence Medical Ethics Committee (ADMEC 97/100).

On the basis that Commanding Officers made particular soldiers available and those soldiers then volunteered to participate, it was implicitly assumed that they were combat ready. Thus, factors such as acclimatisation and illness were not controlled by the scientific team. While this may contribute to variability in performance and strain, it also represents the usual reality of CFAs.

2.2 Standard assessments of physical fitness

The 5 km and 20 km marches of the CFA primarily require aerobic fitness, whereas the other modules require combinations of static and dynamic strength and power. Therefore, traditional tests of aerobic and certain strength and power components of physical fitness were conducted to determine whether performances in CFA modules were closely related to traditional measures of fitness. Close correlations would provide a basis for examining the use of generic measures during assessment of combat related fitness or during selection of Army recruits.

Standard fitness assessments were completed for all soldiers during the afternoon prior to participation in the CFA. The soldiers' morning activities were not controlled, although they were instructed to be well hydrated on arrival for testing. Soldiers were weighed in sports shorts and socks on electronic scales accurate to 50 g (BWB700, Tanita Co., Japan). The grip strength of both hands was then assessed using a hand grip dynamometer, with strength taken as the maximum of 2-3 efforts for each hand.

Anaerobic fitness of the lower limbs was assessed after warm-up using a 30 second, maximum-effort cycle test, on a purpose-designed ergometer (Repco air-braked cycle). Subjects were informed that the peak and total power would be recorded, thereby making the entire effort crucial. This allowed determination of the alactic (explosive) power and lactic (short term) power components of anaerobic fitness.

Aerobic fitness was then assessed using an incremental shuttle run test to voluntary exhaustion (the Beep test). Standard tables were used to equate the number of shuttles completed with their oxygen cost, thus providing an estimate of maximal aerobic power ($\dot{V}O_{2max}$). Thus, although the test used an incremental effort with large muscle groups to the point of exhaustion, there was no direct measure of oxygen uptake ($\dot{V}O_2$) and neither environmental nor pre-test conditions were standardised. Heart rate was recorded by telemetry of the frequency of ventricular depolarisations (Polar SportTester and Accurex, Electro Oy, Finland) at 5 s intervals throughout the test for all subjects. Peak recorded heart rate was used to estimate whether maximum effort was given in the beep test and also to allow heart rates obtained in the CFA to be expressed relative to each individual's peak heart rate (ie. from the Beep test).

2.3 Combat-related assessments of physical fitness

DSTO were involved in data collection and analysis of the following modules of the CFA:

1. 20 km walk with full combat uniform (boots and DPCU: cotton/polyester long-sleeved shirt and trousers[1]), carrying 35 kg load. Time allowed was 4.0 hours. Participants were Infantry soldiers only.
2. 5 km walk with full combat uniform, carrying 20 kg load. Time allowed was 55 min. All Corps participated. The intended load for this module had been 50 kg, as determined by the weight of kit carried during a march-in operation. However, the Commanding Officer of the present (ie. first) trial ruled that 20 kg would be carried.
3. Run-Dodge–Jump (RDJ) activity, with webbing and rifle, as per previous CFAs.
4. Jerry-can carry; lift and carry of two 20 kg jerry cans over a 20 m distance, with no time limit, but also no resettling of the cans en route.

Physiological strain was monitored during the 5 km and 20 km marches only, since remaining modules were too brief to impose significant heat strain.

2.4 Measurement of physiological and psycho-physiological strain

The following physiological and psycho-physiological variables were recorded for the 5 km and 20 km marches ($n \geq 5$, depending on the variable and Corp):

Pre and post:	Urine:	Volume	
		Rate of production	
		Composition:	Specific gravity, pH, total protein, blood, glucose, nitrite, ketones, bilirubin, leukocytes and urobilinogen
		Tympanic temperature	
		Body weight:	Semi nude (with trousers, socks and boots)
			Clothed, with required kit weight
		Perceived body temperature and thermal discomfort	
		Perceived exertion (post only)	
Throughout:		Gastro-intestinal temperature	
		Skin temperature (3 sites plus insulated skin)	
		Heart rate	

[1] DPCU fabric has intrinsic resistances to air and water vapour of 0.02 $m^2 \cdot K \cdot W^{-1}$ and 2.0 $m^2 \cdot Pa \cdot W^{-1}$, respectively (Egglestone and Costa, 1998).

Gastrointestinal temperature (T_{gi}) was measured using three systems (BCTM2, PED Inc., USA; CorTemp, HTI Inc., USA; BFMS, PCD Inc., USA) that are currently being developed for field use. All systems use a pill (HTI, Inc., USA; Koningsberg, PCD Inc. USA) that emits a low power radio signal, the frequency of which is temperature-dependent. The major functional differences between systems are aerial configuration and download software. Soldiers swallowed a pill on the evening prior to participation or immediately after arriving in the morning. T_{gi} has been validated as a measure of core temperature against oesophageal (T_{es}) and rectal (T_{re}) temperature during heat stress (O'Brien et al., 1998).

Tympanic temperature was measured, in triplicate, by infrared thermometer (First Temp®, Genius®, Sherwood IMS 6339, California, USA). Skin temperature was measured using thermistors (Edale Instruments, Cambridge, UK) fastened with a single layer of waterproof tape. Skin temperature was logged by portable logger (Smart Reader 1, ACR Systems Inc., Canada). Mean skin temperature was calculated from the weightings of Burton (1935). Heart rate was measured as described above. Oxygen consumption (O_2) was measured using a portable expiratory-gas analysis system (Metamax®, Cortex, Germany), calibrated before each use with β-grade gas (CO_2 and O_2 analysers) and a syringe (turbine). Energy expenditure ($W \cdot kg^{-1}$) was estimated from O_2 using the non-protein energy equivalent of oxygen at the corresponding respiratory exchange ratio (after Zuntz, 1901, cited in McArdle et al., 1996).

Soldiers were requested to arrive at all sessions in a well-hydrated state, ensured by prior drinking of 2-3 glasses of water more than usual. They were also requested to remember the time of their last urination before providing a baseline urine sample for the 5 km and 20 km marches (which was usually the urination after arising from bed). Urine was sampled by volumetric flask for volume and by dipsticks (Combur[10] Test, Boehringer Mannheim, Germany) for composition.

Baseline bodyweight, including DPCU trousers and boots, was obtained before soldiers were fitted with radio pill receivers, heart rate monitors, skin thermistors and temperature loggers. Soldiers then voided their bladder into a sampling container and were reweighed with their full kit (20 kg or 35 kg). Baseline auditory canal temperature was obtained, followed by perceptions of body temperature and thermal discomfort using scales modified from Gagge et al. (1967). Soldiers then began the march, with instruction to march alone, pacing themselves to simply complete the distance in the required time (55 min or 4 hr).

On completing the march, soldiers provided ratings of perceived exertion (Borg 1962), body temperature and thermal discomfort. Auditory canal temperature was obtained before being reweighed in full kit, voiding of the bladder into a sampling container, removal of loggers and thermistors, and a final weighing in DPCU trousers and boots.

2.5 Data analysis

To ensure that physiological data were obtained from a representative distribution of soldiers within each Corp, soldiers were first ranked according to their aerobic fitness results, then samples were selected from across these distributions. The validity of comparisons between Corps depends on the extent to which the present soldiers are representative of their Corps. While this is unknown, efforts were made to obtain a broad selection of soldiers from each Corp. The uncertain validity applies mainly to the Engineers and Artillery, from which fewer soldiers were available to participate.

The majority of data are presented as histograms to illustrate the distribution and range of responses within and between Corps. Analysis of Variance (ANOVA) and Analysis of CoVariance (ANCOVA) were used to make comparisons between Corps. For example, when comparing between Corps for 5 km march duration, ANCOVA allowed a potentially confounding factor such as the environmental heat stress (Wet Bulb Globe Temperature, WBGT) to be taken into consideration. Differences were taken as statistically significant when the calculated probability of chance occurrence was less than 5%. Differences were isolated using Scheffe's post hoc test. Pearson's correlations were used to determine whether linear relationships existed between variables (eg. body weight and 5 km march time). Such correlations were often limited by the small number of soldiers involved. Paired t-tests were used to compare the level of strain between 5 km and 20 km marches in infantry.

3. Results

Table 1 shows that environmental heat stress during 20 km and 5 km marches was moderate. The work:rest cycles recommended for these temperatures, under the OH&S guidelines for the Australian Army, range from continuous work to a minimum work:rest ratio of 45:15 ($min.hr^{-1}$). The average energy expenditures approximated 633 Watts and 650 Watts for the 20 km (n=3) and 5 km (n=2) marches, respectively. These expenditures required approximately half (52%) of the soldiers' calculated maximum aerobic power and would be considered as heavy but acceptable under mild climatic conditions, but as arduous under the present conditions.

Table 1. *Environmental stress for each endurance activity and Corps. Note that there was a heavy rain shower during the 20 km march. The cooling potential of a fully-saturated DPCU is not reflected in the Wet Bulb Globe Temperature (WBGT) for that exercise. Metabolic rate was derived from relatively few soldiers, thus providing only an indication of heat production.*

	Time *1st start – last finish*	CFA Module	Corp	WBGT °C	Met. Rate *Watts.kg-1*
27/10	0630 – 1155	20 km march	Inf	27.6 ±1.1	7.4 (n=3)
28/10	0630 – 0920	5 km march	Inf	27.8 ±1.3	6.6 (n=2)
29/10	0630 – 0800	5 km march	Art, Eng	24.6 ±0.5	6.1 (n=1)
29/10	0900 – 1150	5 km march	Arm	28.9 ±0.8	8.4 (n=2)
	Average for 5 km march			27.1	7.2 (n=5)

The mean (± SD) weight of soldiers was 79.8 ± 10.5 kg (n=64) and did not differ between Corps (p=0.93).

3.1 Performance in CFA modules

The average (mean ± SD) weight carried in the 20 km march was 35.1 ± 0.5 kg (n=30). Figure 1 illustrates that of 31 infantry soldiers who began this march only 18 (58%) completed the entire distance. Furthermore, only half (9) of these completed the distance within the allocated 4 hours. Thus, only 29% of the soldiers passed this phase of the CFA. As shown in Table 1, the WBGT averaged 27.6°C during this activity, with a brief but heavy downpour providing a substantial cooling effect. Many soldiers rested for 5-10 minutes during each of the four laps, partly on the advice of their CO and the medical officer. It should be noted that some soldiers elected not to walk the final lap because they were unable to complete it within the allocated time. Nevertheless, most soldiers also suffered blistered feet and the blistering was responsible for some attrition. Of the 17 soldiers who were questioned before the 5 km march on the following day, 16 acknowledged blisters or hot spots from the 20 km march. Therefore, prevention of blisters appears to be a significant factor governing the effective range and day-to-day readiness of infantry patrolling in the heat, particularly given that speed of a unit is limited by the speed of the slowest members.

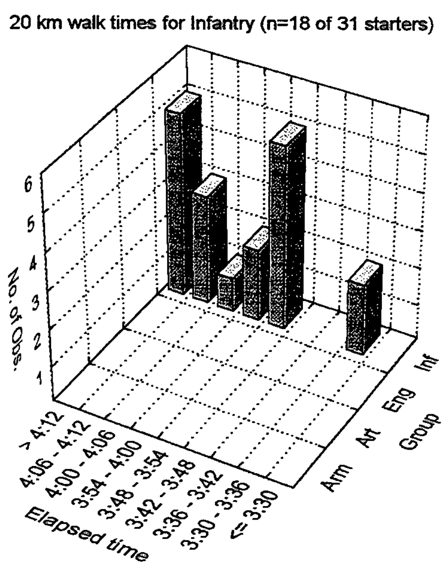


Figure 1. *The distribution of times taken to complete the 20 km march whilst carrying 35 kg. Data are included for only 18 of the 31 infantry soldiers, since the remainder did not complete 20 km. Nine soldiers completed the distance within the 4 hours allocated.*

The intended load weight for the 5-km march was 20 kg. The actual load carried averaged 20.3 ±0.9 kg (n=51) and did not differ between Corps (p=0.74). Figure 2 shows the distribution of times taken to complete the 5 km march for each Corps. The mean duration was 48.40 ± 4.38 min, with 47 of the 51 soldiers (92%) completing the distance within the allocated 55 min. There was no difference between Corps in average march time (p=0.56), despite the differences in environmental heat load (Table 1). There was a poor correlation (r=-0.10, p=0.72, n=13) between 20 km and 5 km march times, probably due in part to the soldiers not being encouraged to complete the distances as fast as possible. That policy has merit from an operational perspective, but the cost within these validation trials is an inability to determine whether 20 km performance might have been predicted accurately from 5 km performance.

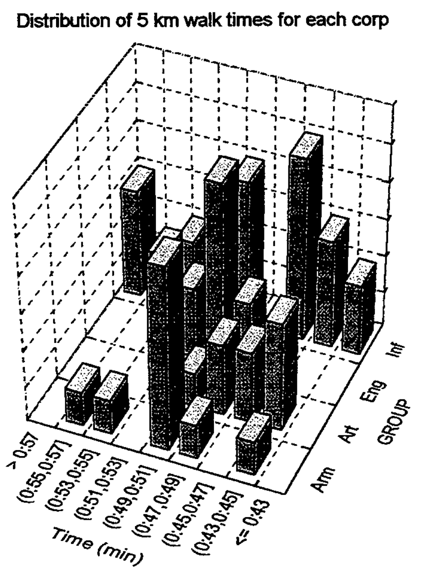


Figure 2. *The distribution of times taken for each Corps to march 5 km whilst carrying 20 kg. 47 of the 51 soldiers (92%) completed the distance within the 55 min allocated.*

Figure 3 shows the distribution of times for completing the Run-Dodge-Jump (RDJ) for each Corps. The overall mean duration was 1.38 ± 0.26 min (n=50), ranging from 1.11 min to 3.15 min. Whereas all Corps had soldiers who completed the RDJ rapidly, the Artillery and Engineer Corps were conspicuous in having slow performers. On average, Engineers (2.02 min) were slower than Infantry (1.25 min, p=0.0017) and Armour (1.27 min, p=0.015) soldiers. The large variability in performance times in the RDJ (Figure 3) is possibly due to the repeated efforts required by some soldiers to scale the wall.

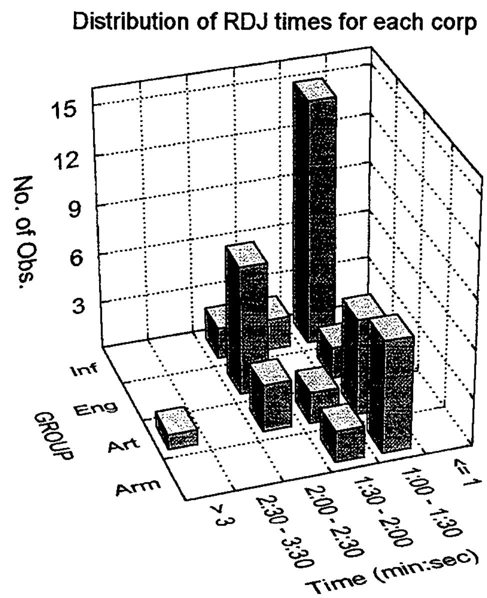


Figure 3. The distribution of times taken for each Corp to complete the Run-Dodge-Jump (RDJ) whilst carrying 20 kg. On average, Engineer Corps took longer than Armour and Infantry Corps.

3.2 Performance in standard fitness tests

Grip strength of the right hand (52.9 kpf) was an average 3.4% greater than the left hand (51.2 kpf, p=0.004), which is consistent with the population tendency for right handedness. Right hand grip strength was equivalent between Corps (p=0.42).

There were no differences between Corps for mean anaerobic power over 30 seconds (750 ± 9 W, n=65, p=0.44), peak power (1009 ± 155 W, n=65, p=0.61), or time taken to reach peak power (5.4 ± 1.8 sec, n=64, p=0.47). The power scores should be interpreted relative to body weight, since soldier's physical activities normally require body weight to be supported or lifted. Peak and mean power were 12.7 ± 1.9 $W.kg^{-1}$ and 9.4 ± 1.0 $W.kg^{-1}$ respectively. These performances cannot be interpreted relative to norms for civilian populations because the air-braked cycle was not calibrated immediately prior to or during tests, and because there is a large discrepancy in the published norms. That is, the present average mean and peak power scores exceed the 99th percentiles compiled by Maud and Shultz (1989) from 60 habitually-active males, but are comparable to the average scores compiled by Telford et al. (1987) from trained and untrained males (peak power of 11.8-14.3 $W.kg^{-1}$ and mean power of 8.1-9.4 $W.kg^{-1}$), and are lower than the peak power of 17.0 ± 2.3 $W.kg^{-1}$ measured from 42 sprinters and professional Australian footballers by McKenna et al. (1987).

Figure 4 shows the maximal aerobic power (~ aerobic fitness) values calculated from the beep test performances. The average score (45.5 ± 6.0 mL.min^{-1}.kg^{-1}) did not differ between Corps (p=0.62) and was similar to the mean reported for a cross-section of healthy civilian individuals (40-45 mL.min^{-1}.kg^{-1}) by Shvartz and Reibold (1990). The highest score (59 mL·min^{-1}·kg^{-1}) was comparable to that of a sub-elite endurance athlete, but there were also scores (33 mL·min^{-1}·kg^{-1}) indicative of below population-average endurance fitness. The average peak heart rate during this test (194 ± 8 bpm, n=61) was equivalent to the maximum heart rate typical of this age group (~197 bpm). Therefore, beep test performances were likely, on average, to reflect genuine maximum efforts. Interestingly, peak heart rate was lower for Engineers (189 bpm) than Infantry (201 bpm, p=0.013), possibly due to lower motivation (competitiveness) or the small sample size of Engineers (n=11).

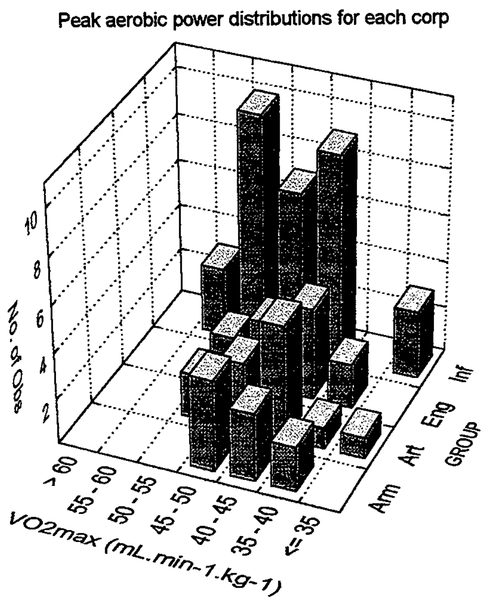


Figure 4. *Distributions of maximum aerobic power for each Corps, as estimated from the Beep test. There was no significant difference in the means of the four Corps (p=0.62).*

3.3 Comparison of standard fitness and combat fitness assessments

3.3.1 Endurance

Since several anthropometric and physiological factors will affect endurance performance during load carriage in the heat, it was originally intended to examine the correlations of the measured variables (separately and in combinations) with 5 km and 20 km performance scores. However, performing these analyses was illogical due to the large influence on times caused by blisters, the relatively small sample size, and the soldiers having received instructions or advice to pace themselves to simply complete the distance in the allocated time.

3.3.2 Strength and Power

Grip strength, and particularly grip strength endurance, is important for carriage of equipment such as jerry cans. However, grip strength was not a useful predictor of soldier performance in the jerry-can carry since all soldiers were able to complete the task for both hands despite a wide range of grip strength (34 - 80 kpf). It can therefore be suggested only that soldiers (or recruits) with a grip strength of at least 34 kpf are probably capable of carrying 20 kg jerry cans over a 20 metre distance.

Successful completion of the RDJ requires technique (learning), lower and upper body strength and power, agility and aerobic power. Therefore, it is not surprising that no single personal attribute could account for RDJ performance. The only significant ($p<0.05$) predictor was $\dot{V}O_{2max}$, and this accounted for just one-fifth of the variability in RDJ scores. Similarly, the only logical predictive equation using multiple personal attributes involved $\dot{V}O_{2max}$ and weight-normalised peak anaerobic power, but the accuracy with which this predicted RDJ scores was poor (± 24 s).

3.4 Strain experienced

3.4.1 Thermal and cardiovascular indices

The 20 km march caused gastrointestinal temperature (T_{gi}) to reach a mean of 38.7°C (range 38.5°C to 39.7°C, n=5). Three points are pertinent regarding these responses. Firstly, they reveal substantial differences between soldiers in ability to counter the thermal stress, highlighted by the T_{gi} elevations ranging from 1.1°C to 2.6°C. Secondly, their practical significance is unclear when interpreted in isolation. Well-trained athletes typically show equivalent or higher temperatures, yet untrained civilians would rarely experience such hyperthermia. Thirdly, they should be interpreted with consideration of other indices of strain, particularly cardiovascular strain. The most relevant measure is heart rate, expressed relative to the individual's peak heart rate ($\%HR_{peak}$). Because heart rates were relatively stable throughout the 20 km march, and the average maximum $\%HR_{peak}$ was 89% (range 83% to 95%, n=10), this module was clearly strenuous for all soldiers and very strenuous for some.

The shorter duration and lighter load in the 5 km march caused slightly less heat strain. That is, T_{gi} for Infantry soldiers rose to 38.4°C (range 37.7 to 39.1, n=7). Figure 5 shows that the average rise in T_{gi} was less for Armour (0.9°C) than for Infantry (1.6°C) soldiers (p=0.03). The tympanic temperature, while not a good absolute measure of core temperature, also showed high elevations for Infantry. These findings were partly due to the Armour soldiers already having elevated core temperature before the march (T_{gi} = 37.8°C, versus 36.9°C for Infantry), highlighting the need for greater standardisation of soldier activities immediately before and during validation trials.

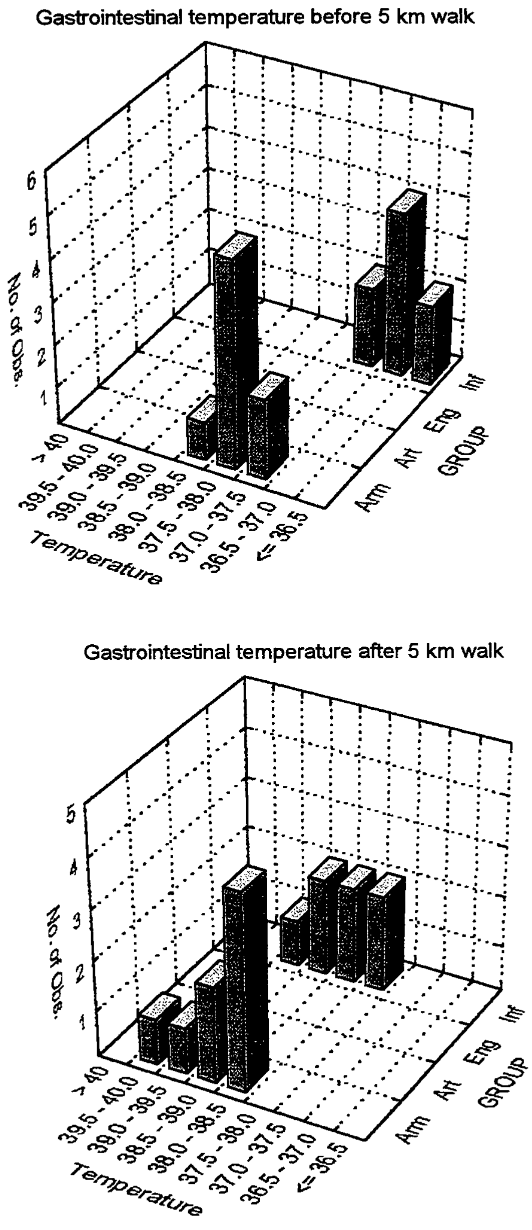


Figure 5. *Gastrointestinal temperature immediately before (top panel) and after (bottom panel) the 5 km march for each Corps. Note the high core temperature for Armour soldiers prior to onset, presumably due to a later start time and their participation in pre-trial physical activity.*

Figure 6 shows that cardiovascular strain during the 5 km march was high, averaging 83% HR_{peak}. These % HR_{peak} were close to those of the 20 km march and were equivalent between Corps (p=0.21). The trend for higher rates among the Infantry (87.4% HR_{peak}) is consistent with their tendency for higher thermal and psychophysical strain (described below).

The brief but heavy rain during the 20 km march provided considerable cooling, and almost masked the additional strain caused by the distance and pack weight being greater than in the 5 km march. This confounding effect was most clearly shown by the mean skin temperatures, which increased by an average of 1.6°C in the 5 km march, but actually decreased by 0.6°C in the 20 km march (p=0.014, n=5 for 5 km versus 20 km).

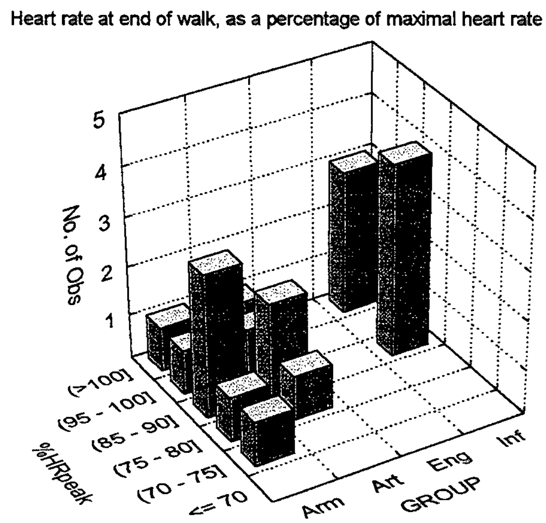


Figure 6. *The distribution of heart rate responses for each Corps within the 5 km march. Heart rate is expressed relative to the individual's maximum heart rate. Note the high average cardiovascular strain.*

3.4.2 Weight loss and urinary indices

Pre- and post-march urine samples were obtained from 30 soldiers. The pre-march samples revealed - from rate of urine production - that many soldiers were hypohydrated at the onset of the CFA, despite the instruction to ensure adequate pre-hydration. Figure 7 shows that although the average baseline rates of urine production were generally adequate for Artillery soldiers (106 $mL.hr^{-1}$, n=11), they tended to be lower for Armour soldiers (47 $mL.hr^{-1}$, p=0.09, n=9), and were significantly so for

Infantry soldiers (24 mL.hr-1, p=0.01, n=9). The physiological strain, psychophysical strain and endurance performance of Infantry were therefore likely to have been affected to a greater extent by their poorer hydration status, which may have been due to the 20 km march on the previous day. The specific gravity of urine, which tends to increase with hypohydration because of reduced free water excretion, did not differ between Corps or between the start and end of 5 km or 20 km marches (all $p \approx 0.1$). The null findings are possibly due to poor sensitivity of the method used in these trials rather than reflecting actual hydration status.

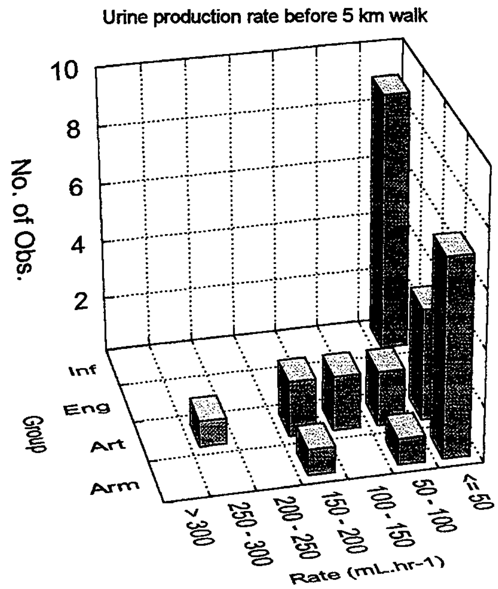
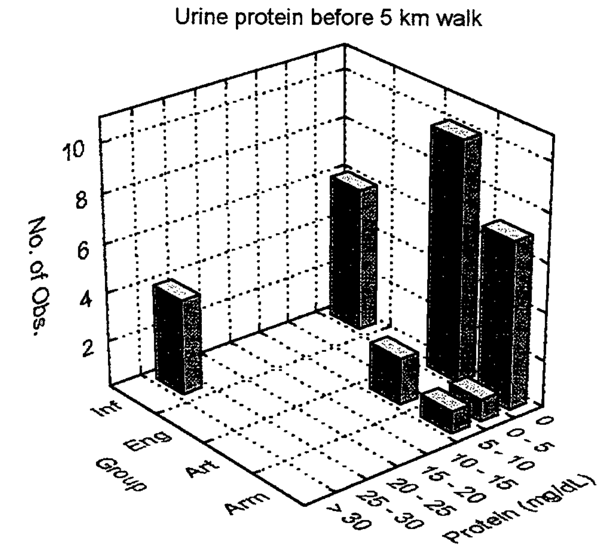


Figure 7. Distribution of urine production rates for each Corps prior to starting the 5 km march. The average rate for Infantry is conspicuously low, indicating a baseline hypohydration.

Net body weight loss, and therefore dehydration, during the 5 km march averaged 370 mL (n=49). It ranged from a loss of 1200 mL to a gain of 800 mL. Therefore, while average dehydration was relatively inconsequential, at only 0.5% body weight, the one-in-five (9/48) soldiers with dehydration greater than 1% body weight would presumably have had some impairment to physiological function and march performance (Sawka, 2000). The dehydration was not different between Corps (p=0.09) and was not (measurably) affected by WBGT. Unexpectedly, it was not significantly greater with the 20 km march (360 ± 820 mL, or 0.45%) than the 5 km march (150 ± 580 mL, or 0.19%, n=15, p=0.21). However, this comparison is limited because of the small sample (n=15) for whom data was obtained from both marches, and because of the rain experienced during the 20 km march.



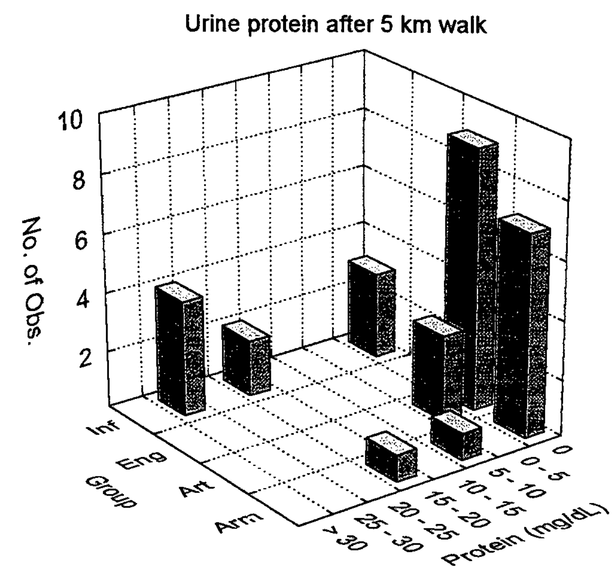


Figure 8. The distribution of urinary protein concentrations for each Corps before (top panel) and after (bottom panel) the 5 km walk.

Total weight loss during the marches was variously affected by rain, periodic showering of soldiers with hoses en route, and by the practice of pouring water from water bottles onto their skin. Therefore, total weight loss was unsuitable for meaningful analyses.

Proteinuria was evident in 11 of the 30 soldiers after the 5 km march, although it was seen in 8 of these before the march, as shown in Figure 8. This indicates dietary-related false-positive tests or proteinuria that was unrelated to the exercise. Nonetheless, an incidence of exercise-induced proteinuria of 10% (3/30) is unexpectedly high in view of the relatively light physical demand of the revised 20 kg load weight. Furthermore, during the 20 km march, 3 of 11 soldiers developed appreciable proteinuria (25-30 $mg.dL^{-1}$) - probably indicative of the bilirubin which was present in their urine. Urinary bilirubin signifies excessive chemical or physical stress on red blood cells. Urinary blood content increased during marching in 5 of 41 soldiers who were sampled. The occurrences of these urinary abnormalities were too few for statistical analysis. The fact that they occurred at all indicates that their incidence should be further examined in soldiers carrying heavy but routine loads in the tropics.

3.4.3 Psychophysical indices

On average, Infantry soldiers rated the physical exertion of the 20 km march as 17.55, ranging from hard (15) to maximum (20). Their perceived body temperature averaged hot to very hot, which was rated as very uncomfortable to extremely uncomfortable. Therefore, on average, their perceptions of strain were consistent with the high levels of physiological strain caused by the 20 km march.

These perceptions of strain during the 20 km march were all higher than during the 5 km march (all $p<0.05$ and $n=9$), despite the 5 km march being performed on the day after the 20 km march. Nevertheless, the consecutive day format may have contributed to the trend for Infantry to perceive the 5 km march as more strenuous, hotter, and more uncomfortably hot, than did the other Corps. Infantry had the highest rank average score for all psychophysical variables, though not all results were significant (ie. $p<0.05$). Armour always had the second highest rank average score.

The only statistically significant correlations between psychophysical and physiological indices of strain were in the 5 km march, where perceived exertion was correlated with the rise in tympanic temperature ($r=0.39$, $n=29$, $p=0.04$) and the peak heart rate ($\%HR_{max}$; $r=0.44$, $n=27$, $p=0.02$). Thus, perceived exertion accounted for approximately only one-fifth of these responses. Notwithstanding the modest sample sizes, it might therefore be suggested that soldiers' perceptions of strain may not provide an accurate indication of their physiological strain.

3.4.4 Individual strain

The limitation with presenting grouped data, particularly for each variable separately, is that soldiers with severe or persistently high strain are overlooked. For instance, Table 2 shows multiple indicators of very high strain for one Infantry soldier.

Interestingly, this soldier was among the minority who reported no overt instances of heat strain or heat-related problems during previous duties.

Table 2. Indices of physiological and psychophysical strain before and after the 5 km and 20 km marches for one Infantry soldier. Thermal discomfort level 4 = very uncomfortable. Perceived exertion level 17 = very hard. All indicators of strain were very high following the 20 km march, with the exception of mean skin temperature, which was reduced by the rain.

	5 km march		**20 km march**	
	Pre	Post	Pre	Post
March time (h:min)		0:49		3:56
Heart rate (bpm; HR_{max}=199)		160		180
Core temperature (T_{gi}; °C)	37.5	39.0	37.1	39.7
Mean skin temperature (°C)	34.1	35.8	33.8	32.4
Urinary blood (cells.μL^{-1})	0	5	0	250
Urinary bilirubin (-, + or ++)	-	+	-	++
Perceived exertion	Nil	17	Nil	17
Temperature sensation	Neutral	Hot	Neutral	Very hot
Thermal discomfort (0 to 5)	0	4	0	4

4. Discussion

Although one aim of the trials was to validate the prototype CFA, absolute validation is not possible since there is no criterion measure of combat fitness available against which to compare the present CFA performance scores. Therefore, it must be assumed that the physical demands of the CFA modules adequately represent those likely to be required in combat operations. On that assumption, the validation trials examined whether the CFA pass criteria are achievable by soldiers of each army Corps under tropical environmental conditions.

Less than one-in-three Infantry soldiers completed the 20 km march in the 4 hours allocated. The high failure rate was probably due to a combination of foot skin and boot problems, inadequate endurance fitness and moderate environmental heat stress (mean WBGT = 27.1°C). Indexing the pass time to the level of environmental heat stress (eg. WBGT) seems necessary. It can not be determined from the present data because the experiment was not designed to provide such information. A suitable index to use in the interim may be the Army's recommended work:rest cycles for different WBGTs, ie. ~11% per °C, based on Mathews (1985). This weighting is several-fold higher than is observed in athletic competition, where the effect of WBGT on endurance performance has been reported as being ~0.3% per °C (McCann and Adams, 1997). Therefore, an appropriate index for use during fully-clothed marching needs to be determined, based on heat strain data obtained under well-regulated WBGTs in the laboratory.

The majority of soldiers (92%) completed the 5 km march within the 55 minutes allocated, and all soldiers completed the distance within 1 hour. As stated above, the Commanding Officer had determined that soldiers would carry only 20 kg rather than the intended 50 kg. Therefore, while pass rates in this module were high for all Corps, it is doubtful whether the module actually provides a valid assessment of its operational counterpart, the fully-kitted march in. For instance, the high strain experienced by many soldiers while carrying 20 kg of kit in these humid conditions would have been substantially compounded if carrying 50 kg. The latter was identified by DHSB, in consultation with 3 Brigade, as a realistic load during march-in. In view of the strain experienced with 20 kg load carriage and the incidence of foot problems from the 20 km march, the physiological, cognitive and performance consequences of carrying heavy loads remain notably undetermined.

Despite the lighter (20 kg) load, there were still instances of blood in urine, in association with high core temperatures, thermal discomfort and perceived effort. While some cases of proteinuria were probably unrelated to the CFA (dietary or disease factors), there was at least one case of renal dysfunction likely to have arisen from the CFA (Table 2). Therefore, it is recommended that the prevalence and severity of proteinuria and urinary bilirubin and blood, as indicators of renal filtration integrity and red blood cell stress, should be further examined. In particular, these examinations should be on soldiers carrying heavy but routine loads in the tropics and for whom a dietary record is obtained.

Infantry are often regarded as being the Corps having greatest endurance fitness. However, across standard and combat fitness assessments, infantry outperformed other Corps only in the RDJ, and this was only relative to Engineers and perhaps Artillery. Furthermore, Infantry soldiers consistently showed the highest average levels of physiological and psychophysical strain. It is unlikely that these findings are due to a bias associated with the soldiers who volunteered for physiological monitoring. These soldiers were screened on the basis of aerobic fitness to ensure a good spread of individuals from the entire Infantry group of CFA volunteers. However, it is quite possible that a bias existed in terms of the calibre of soldier attending the CFA from each Corps, in that a broader spectrum was represented for Infantry. Furthermore, the 20 km march was performed by Infantry only, and the effects of the 20 km march would have had an impact upon the 5 km march and possibly the RDJ.

One aim of the trials was to examine mathematically which personal attributes or combination of attributes could account for performance in CFA modules. These analyses were unable to be performed for the 5 km and 20 km marches because of the relatively low number of soldiers involved and the manner in which soldiers completed the marches (using up available time or pairing-up during the marches). While RDJ performances did not suffer this problem, the skill and fitness demands of the RDJ are complex. Thus, unsurprisingly, RDJ performance was not satisfactorily explained by the personal attributes that were measured. Finally, success in the jerry-can carry was 100%, which again means that performance was unable to be predicted from the measured variables. Assuming the 20-m jerry-can carry aims to assess the capability of soldiers to move equipment, then it may be pertinent to make this module more task specific. This might be achieved using a repeated lift and carry at a minimum required rate.

The average aerobic fitness appeared to be little or no better than among age-matched counterparts of the civilian population. Since aerobic capacity can usually be improved by only 10-20% with endurance training (DeVries and Housh, 1996), the present sample of soldiers were either of only population average fitness at time of recruitment or had not appreciably increased their aerobic capacity since recruitment. Although this conclusion is limited by the validity and reliability of the present estimates of aerobic fitness, this is unlikely to affect the conclusion substantially. The extent to which the limited fitness applies generally to Army Corps will become evident from further CFA trials. The issue is important, since endurance fitness is probably the largest single determinant of heat stress tolerance (Armstrong and Pandolf, 1988) and is essential for individual and unit effectiveness during patrolling and extended field operations. Finally, an estimation of adiposity would have been useful in these trials, since this is a determinant of aerobic fitness in relation to weight dependent activities such as walking, running and climbing.

Methodologically, hydration status seemed to be estimated with greater sensitivity by baseline rate of urine production than by urine specific gravity (measured using commercial urine sticks). Core temperature measurement using radio frequency-emitting pills in the gastro-intestinal tract is promising in terms of accuracy of measurement (O'Brien et al., 1998) and acceptance by military personnel. However, there are currently problems due to the early developmental status of this technology and the cost of pills and receivers. Based on anecdotal evidence from this trial, the preferred monitoring system was the BCTM. This unit with accompanying pill, was simplistic in its application, appeared to be the most reliable (i.e. minimal loss of data), user friendly (both device usage and interface software) and relatively compact in comparison to the other systems (CorTemp and BFMS). The capability to store numerous GI-pill ID's during its initial configuration provided greater flexibility and usability than the other devices. Furthermore, the BCTM's internal antenna and overall simplistic approach surpassed the CorTemp's cumbersome external reception harness and the BFMS's complicated receiver and logger module configurations.

In summary, there was a very low pass rate for the Infantry-only module of walking 20 km in 4 hours with 35 kg carried weight. In contrast, there was a very high pass rate for all Corps walking 5 km in 55 mins with 20 kg carried weight. Performances in the RDJ were variable within and between Corps. All soldiers successfully completed the jerry-can carry module. Physiological and psychophysical strain were variable between soldiers, with some cases of moderate-to-severe heat strain. The strain tended to be higher among Infantry, although this may have been due to a more representative cross-section of soldiers from that Corps, and the additional endurance module on which they were assessed. The high strain evident from the 5 km march with 20 kg carried weight indicates that CFA performances probably overestimate soldiers' ability to complete a march-in with full kit (ie. at least 45 kg).

5. Recommendations

1. The pass times for the 20 km and 5 km marches should be indexed to environmental heat stress (eg. WBGT). An appropriate index could be determined empirically from the literature and from laboratory studies. In the interim, the Army's OH&S policy of work:rest ratios for heavy work may provide appropriate guidance. Thus, pass times might be:

   5 km: Pass time = 55 min, plus 6 min for each °C WBGT above 25.5°C;
   20 km: Pass time = 240 min, plus 27 min for each °C WBGT above 25.5°C.

2. Soldiers participating in the CFA should be rested and well hydrated prior to participation. While this is most important for trialing of the CFA, it still applies for routine administration of the CFA.

3. There is clearly a requirement for soldiers to be educated in maintaining adequate hydration. Installation of body weight scales into fitness facilities, coupled with training of physical fitness training personnel, may assist this process.

4. Widespread testing of soldiers' aerobic fitness is recommended. This will determine the extent to which current fitness levels may be contributing to heat stress related problems of operating in northern Australia.

5. Finally, it is recommended that physiological and psychophysical strain be examined during routine training in which soldiers march with heavy loads (i.e. at least 45 kg) under heat-stressful conditions. Of particular interest would be the extent to which physiological strain (e.g. core temperature) is related to soldiers' perceived strain, and the extent to which renal function may be affected by sustained load carriage in the heat.

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James D. Cotter, Warren S. Roberts, Denys Amos, Wai-Man Lau and Stephen K. Prigg

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19. ABSTRACT

The Australian Defence Force is improving the operational specificity of combat fitness assessment (CFA). A prototype CFA trial, conducted using 64 male soldiers of 3 Brigade, Townsville, allowed for the evaluation of both the CFA and the severity of heat strain experienced during physical training and assessment in northern Australia. Maximal aerobic (O_{2max}) and anaerobic (peak and 30-s mean) power were estimated by Beep and Wingate tests, respectively. Peak and 30-s mean powers and estimated O_{2max} were 12.7 ±1.9 $W{\cdot}kg^{-1}$, 9.3 ±1.0 $W{\cdot}kg^{-1}$ and 45.5 ±6.0 $mL{\cdot}min^{-1}{\cdot}kg^{-1}$, respectively. Of 31 soldiers marching 20 km with 35 kg load, 9 (29%) finished within the 4 hours available (WBGT =27.6°C). Of 51 soldiers marching 5 km with 20 kg load, 47 (92%) finished within 55 mins (WBGT=27.1°C). Heart rate (HR), VO_2, gastrointestinal (T_{gi}) and skin (T_{sk}) temperature were recorded during the marches (n=5-19). Body weight, urine composition and volume and psychophysical indices of strain were obtained before and after the marches (n=9-50). At completion of the 5 and 20 km marches, high strain was evident from high HR (mean = 83% [5 km] & 89% [20 km] of HR_{max}), T_{gi} (38.6°C & 39.1°C), perceived body temperature (hot and very hot) and exertion (very hard and hard), and by instances of urinary protein and erythrocytes. The present estimates of O_{2max} indicate that the ability of these infantry to operate in the tropics may be appreciably limited by their aerobic fitness. Further testing of soldiers' aerobic fitness will help determine the extent of this problem. Similarly, some soldiers experience very high heat strain during training and assessment. Endurance-related assessments should be conducted with personnel being rested and well hydrated, and with performance being indexed to environmental heat stress. Finally, heat strain can be monitored using gastro-intestinal radio-pill thermometry where appropriate.

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